

An Excellent Method to Lay Out ISA100.11a Field Wireless Devices

Kiyoshi Takai ^{*1} Kiyotaka Aikawa ^{*1}
Mai Hagimoto ^{*1} Kouji Watanabe ^{*1}

We have identified an excellent method to lay out ISA100.11a field wireless devices, which is applicable to any field. With this method, optimal wireless communication can be achieved. We call this simple method, the “Sky Mesh” method. This paper explains how to arrange field wireless devices in accordance with the Sky Mesh method and describes the result of an actual installation in a plant.

INTRODUCTION

In plant sites, there are various places such as those affording an unobstructed view like tank yards, and others surrounded by metal pipes and equipment obstructing the view (hereafter referred to “pipe jungles”), often seen in oil refinery and chemical on-site plants. The frequency band of radio waves used for field wireless communication is 2.4 GHz, which has high straightness and its ability to go around things can hardly be expected. Therefore, the wireless communication over more than 500 m distance is possible only when the line of sight is ensured, otherwise obstacles on the wireless communication path easily degrade its quality, disabling long distance communication. The most troublesome obstacle in actual plants is the pipe jungle, where the line of sight is largely obstructed. However, many transmitters and gauges are installed in such places and the pipe jungle is the very place to introduce field wireless networks. ⁽¹⁾

Under the concept of “Reliable Radio”, Yokogawa has been providing highly reliable wireless products conforming to the ISA100.11a standard, and thereby solved these problems.

In this paper, we propose an installation design method to respond to the requirements for improving field wireless reliability further. This design is called the “Sky Mesh” method, where robust communication paths are secured above a plant by using a group of repeaters, which can be called wireless infrastructure, and the repeaters communicate with field wireless devices installed in pipe jungles. Yokogawa has been successfully applying this method to many plants for

stable field wireless networks. When applying the Sky Mesh method, it is crucial that the communication paths through the repeaters can be fixed. Yokogawa’s field wireless system supports both auto mesh networks and fixed path network, so that the Sky Mesh method can be applied effectively.

We first describe the characteristics of radio wave propagation and indexes for wireless communication evaluation, then describe the Sky Mesh method, which can be applied for optimal device installation in plants, and finally we demonstrate an example of its successful application to an actual plant.

PROPAGATION CHARACTERISTICS OF RADIO WAVES OF 2.4 GHz BAND

Understanding radio wave propagation characteristics is important for installing field wireless devices in field sites. The most important points among the characteristics of the 2.4 GHz band ⁽²⁾ are summarized in the following sections. In particular, the issues shown in the title of the following three sections should be considered when installing field wireless devices at sites.

Attenuation Rate through Radio Wave Propagation

Free space propagation is radio wave propagation through space where no obstacles or reflecting objects exist around transmitting points or terminals. Strictly speaking, it is propagation with no other waves except for direct waves as in cosmic space or anechoic chambers.

Free space propagation loss is expressed by the equation (1), and it increases in proportion to the square of the distance between the transmitting point and the receiving point. This is the basis even when considering other more complicated cases.

^{*1} Business Planning Division,
Industrial Automation Marketing Headquarters

$$L_{fs} = -(20\log_{10}f + 20\log_{10}d + 20\log_{10}\left(\frac{4\pi}{C}\right) + 120) \dots\dots\dots (1)$$

L_{fs} : Free space propagation loss [dB]

f : Frequency [MHz]

d : Distance between the transmitting point and the receiving point [m]

C : Light speed [m/s]

Figure 1 shows the graph of the result obtained by assigning the frequency of 2400 MHz (2.4 GHz), which is used in the ISA100.11a standard, into f in the equation (1).

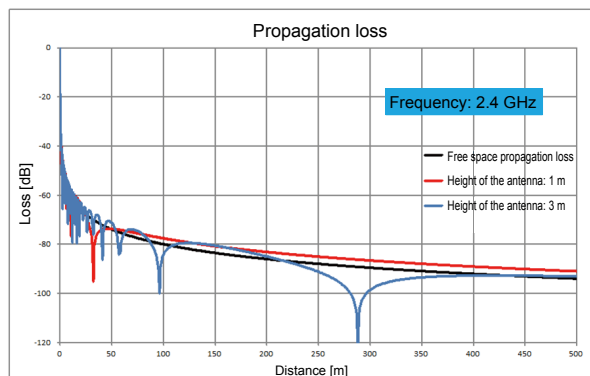


Figure 1 Free space propagation loss and propagation loss including the effect of ground surface reflection

The following equation holds when the output power is 10 mW (10 dBm), the antenna gain of both the transmitter and receiver is +2 dBi, and the communication distance is 500 m at which the propagation loss is -94 dB.

$$\text{Receiving level} = 10 \text{ dBm} + 2 \text{ dBi} - 94 \text{ dB} + 2 \text{ dBi} = -80 \text{ dBm}$$

ISA100.11a refers to the receive sensitivity as -90 dBm or less, and thus the receiving level described above is sufficient for demodulating the signal.

Actually, however, antennas are installed not far from the ground and thus wave propagation is affected by the ground surface. Some radio waves transmitted from a transmitting antenna propagate directly to a receiving antenna while others propagate being reflected by the ground surface, and these waves overlap each other, causing interference. Figure 1 shows the relationship between the communication distance and propagation loss when antennas are installed at 1 m and 3 m from the ground respectively. For long distance communication, interference can be reduced by lowering the installation height of an antenna, nevertheless the communication quality may degrade in the Fresnel zone described in the following section.

The Fresnel Zone

In most cases, the theory of free space propagation loss cannot be applied to actual situations. This is because the ground and structures around antennas always exist even where the line of sight is ensured.

In wireless communication, the theory of free space

propagation loss is applicable when no obstacles exist in the zone around the straight line between two antennas. This spheroid zone shown in Figure 2 is called the Fresnel zone. Any obstacles in the Fresnel zone increase propagation loss and deteriorate the quality of wireless communication.

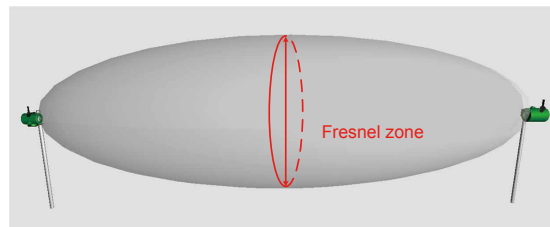


Figure 2 The Fresnel zone

Diffraction and Reflection

In actual layouts, as shown in Figure 3, still more buildings and other structures exist and they cause reflection and diffraction of waves. The frequency of 2.4 GHz for wireless communication is relatively high and its wavelength is about 12 cm, thus much diffraction effect cannot be expected in pipe jungles that comprise structures of a few meters to a few dozen meters in size.

On the other hand, reflection effect can be expected in plants because most of their structures are made of metals that reflect radio waves. Thus, the communication is often possible even when there exist obstacles in the communication path and the line of sight is not available. Yokogawa's experience has proven that the reflection effect helps obtain good communication quality even in pipe jungles where the line of sight is not available as far as the communication distance of up to 50 meters.

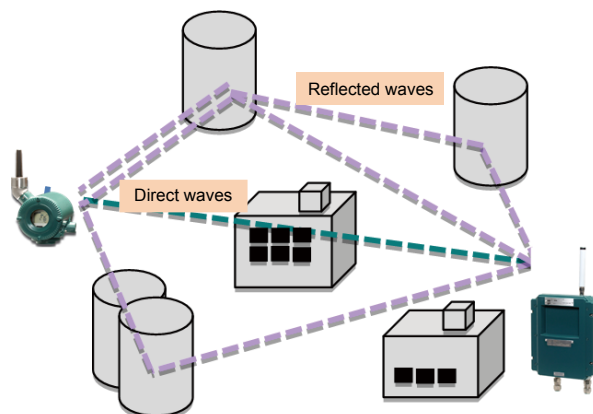


Figure 3 Reflection of radio wave

EVALUATION INDEX FOR WIRELESS COMMUNICATION

Bit error rate (BER) is commonly used for evaluating the performance of field wireless devices. BER is measured by checking which bits are received incorrectly during the communication of predetermined bit patterns. Therefore, a

dedicated program has to be installed in the devices, and the analysis requires a considerable amount of processing. For this reason, single-purpose instruments are usually used for BER measurement.

In contrast, packet error rate (PER) is the ratio of incorrectly received packets to the whole packets transmitted. This measurement can be done during normal data communication without any special tools, so it is suitable for evaluation of wireless communication in actual conditions.

Communication quality is also estimated by evaluating the received signal strength indication (RSSI). PER can be estimated from the RSSI value in ideal free space described in the “Attenuation Rate in Wave Propagation” section, or in the environment less influenced by obstacles. However, as shown in Figure 4, obvious correlation between RSSI and PER cannot be found at actual sites, especially in pipe jungles.

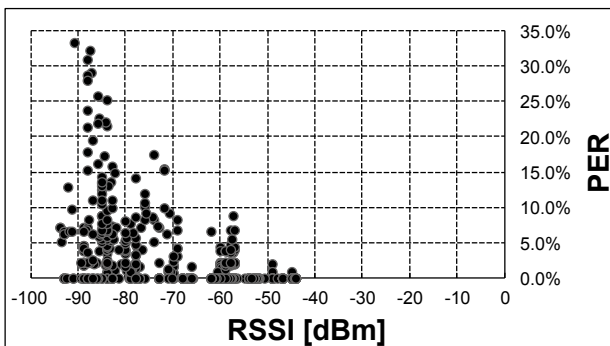


Figure 4 Relation between PER and RSSI at actual sites

PER is the most fundamental index for evaluating wireless communication in plant sites. When designing the total field wireless system, the number of retries necessary to achieve reliability can be determined by the known PER. The number of retries, combined with information on communication paths, enables us to estimate the entire system reliability, delay time for a packet to travel from a field wireless device to the host system, and the lifetime of batteries in each field wireless device.

For these reasons, Yokogawa commonly uses the PER index for evaluating wireless communication. However, the discussion above is applicable only when communication paths are predictable.

DESIGNING BASED ON SKY MESH METHOD

When laying out field wireless devices in an actual plant, the most difficult location to design is a pipe jungle with pipes and equipment tangled, which is often seen in oil refinery on-site plants.

Wireless access points are usually installed on rooftops of control rooms or similar facilities. Meanwhile, field wireless devices are installed in pipe jungles because their measurement targets are located in the midst of them. In such places, the line of sight is limited and there exist many reflected waves from surrounding structures. In addition,

the distance between the field wireless device and the access point often exceeds 400 m. Therefore, it is difficult to establish direct wireless communication.

In the area of a pipe jungle at plant sites, tall towers such as distillation columns are usually built. In most cases, the location near the top of such structures can provide a direct line of sight to the rooftop of control rooms where wireless access points are installed and it is possible to secure the Fresnel zone in the space between them, so that this location is ideal for wireless communication with access points. Installing wireless repeaters near the top of these towers as shown in Figure 5 is expected to achieve good communication quality. It is empirically proven that satisfactory wireless communication quality is ensured if the distance between a repeater at a height of about 30 m and a field wireless device at the measurement point is less than 50 meters. This is because reflected waves by metal structures can improve the communication quality even when the line of sight is not ensured. However, the case where the communication distance in a pipe jungle exceeds 50 m should be paid attention to, since the communication quality is poor in most of such cases.

As described above, installing repeaters in high places can ensure the Fresnel zone for communication with wireless access points. In addition, this eliminates the fear that men, vehicles, or other obstacles might block the communication path. In wireless communication, redundant paths to the host system are secured for reducing the possibility of communication failure caused by the obstacles in the communication paths. The Sky Mesh method enables us to presume what may cause communication failures from this viewpoint.

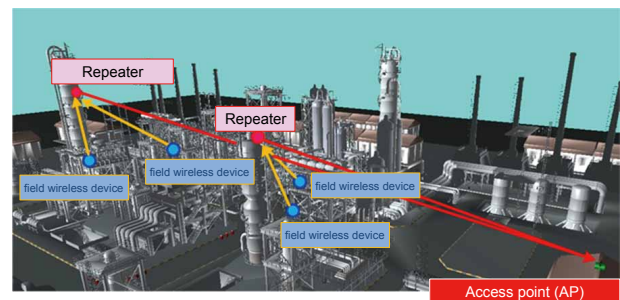


Figure 5 Conceptual configuration diagram applying the Sky Mesh method

APPLICATION OF SKY MESH METHOD TO A PLANT

The effectiveness of the installation design by the Sky Mesh method was verified in an actual plant.

Field Wireless Device Layout in Plant

Figure 6 shows an actual layout of field wireless devices in a plant.

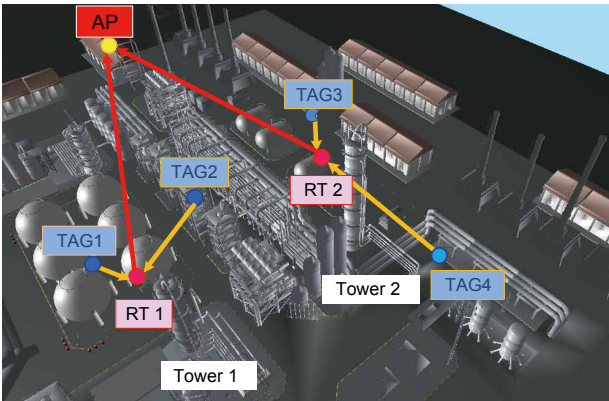


Figure 6 Verified layout image in a plant

The antenna of a wireless access point (AP) is installed about 2 meters above the rooftop of the one-story control room. Four antennas of the field wireless device at measurement points (TAG 1 through TAG 4) in a pipe jungle are up to 400 meters away from the control room.

Layout Design

There are two towers (Tower 1 and Tower 2) within 50 meters of the four field wireless devices. Two repeaters (RT 1 and RT 2) are installed on the top of Tower 1 and Tower 2, respectively, because those points can ensure the line of sight to AP and the Fresnel zone can be secured. Although the line of sight from TAG 1 or TAG 2 to RT1 is not available, we have concluded that there would be no difficulties in establishing wireless communication because both points are within 50 meters of RT 1. Likewise, we expected good communication between TAG 3/ TAG 4 and RT 2.

Evaluation Result of Wireless Communication

Figure 7 shows the system topology and the PER and RSSI values of each path obtained through approximately 1000-packet communication.

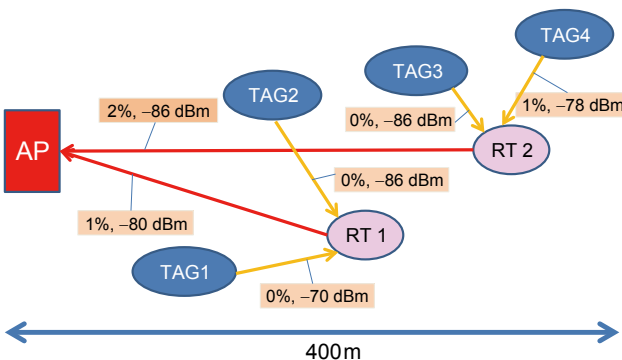


Figure 7 Evaluation result of wireless communication

Discussion

Table 1 shows the communication reliability for each

path derived from the PER values of each path shown in Figure 7.

Table 1 PER values of each path and communication reliability for each path

Measurement point	Path 1	PER	Path 2	PER	Error rate	Communication reliability when 4 tries are performed
TAG1	TAG1 → RT1	0.0%	RT1 → AP	1.1%	1.1%	99.9999985%
TAG2	TAG2 → RT1	0.0%	RT1 → AP	1.1%	1.1%	99.9999985%
TAG3	TAG3 → RT2	0.0%	RT2 → AP	1.8%	1.8%	99.9999895%
TAG4	TAG4 → RT2	0.9%	RT2 → AP	1.8%	2.7%	99.9999469%

As shown above, a packet transmitted from TAG 1 reaches RT 1 with 0% PER and then reaches AP with 1.1% PER. This means that 1.1% of the whole packet does not reach AP if there is no retry. In other words, when TAG 1 sends data to the host system 1000 times, data loss happens 11 times. In fact, retries are always performed. For example, in a system with Yokogawa’s YFGW 710 field wireless integrated gateway, 4 retries are performed when the data update cycle is set to 10 sec, and the communication reliability is calculated by subtracting the fourth power of 1.1% from 1. Even for communication from TAG 4 with the worst error rate, the resulting reliability is higher than 99.9999%.

With the topology described above, however, the data from field wireless devices connected to a repeater cannot be obtained if the repeater fails, or during the change of its battery. To prevent such inconvenience, an additional repeater can be installed adjacent to each repeater. This configuration doubles the communication reliability.

CONCLUSION

We have applied the Sky Mesh method to the actual designing of a field wireless device installation and obtained satisfactory results.

Generally, the reliability of wireless communication is said to be incomparably lower than wired communication. In fact, the BER of wired communication is high at the physical layer level. However, wireless communication circuits are rapidly evolving, and sufficient communication reliability is ensured by improved signal processing or retries. Further improvement of technology including that for communication systems will help wireless communication catch up with wired communication in terms of reliability soon.

Meanwhile, as the characteristics of radio waves for wireless communication remain unchanged; so will the importance of installation design.

REFERENCES

- (1) Tsuyoshi Yoshioka, “Targets of Field Wireless Devices,” Instrumentation control engineering, Vol. 54, No. 10, 2011, pp. 21-25 in Japanese
- (2) Seiichi Sampei, “Digital Wireless Transmission Technology - From Basics to System Design,” Pearson Education, 2002

* YFGW is a registered trademark of Yokogawa Electric Corporation.